Incense and imagery: mapping agricultural and water management systems on the island of Socotra, Yemen

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Summary

Situated at the entrance to the Red Sea, the island of Socotra features prominently in historical texts as an important source of exotic resources such as incense, Indian cinnabar (dragon's blood), and aloes. The intensive cultivation of these products, particularly during the first centuries BC/AD, has been suggested as the reason for an extensive set of walls and enclosures found across the island. The extent and function of these systems has yet to be adequately examined or explained. In this paper, we demonstrate how the mapping of these walls using the remote sensing of satellite imagery together with the evidence from ecological, archaeological, and historical studies has now made it possible for us to begin to understand how these systems may have functioned. The preliminary results of this work will show that the walls not only served a variety of functions pertaining to the agricultural production and management of incense, dragon's blood, and aloes, but that they were also being used in water and soil management practices.

Keywords: Socotra, incense, aloes, dragon's blood, satellite imagery.

Introduction

The island of Socotra, situated approximately 135 nautical miles (naut. m.; 250 km) north-east of Cape Guardafui, Somalia, and 205 naut. m. (*c*.380 km) south of RaMs Fartak, Yemen, is well known as being among the principal producers of frankincense, Indian cinnabar (dragon's blood), and aloes. Claims that Socotra supplied the world with these commodities may be found in the historical texts of Herodotus (*c*. fifth century BC) in *Histories* (1920–1957: 2.3.107–112), Diodorus Siculus (*fl*. *c*. first century BC) in *Bibliotheca Historica* (1933–1967: 5.41.4, 5.42.5), Pliny the Elder (*c*. first century AD) in *Historia Naturalis* (1969: 6.32.153, 6.34.170, 6.36.153), and Ptolemy (*c*. first century AD) in

Geographia (1990: 6.7.45, 8.22.17). Whereas the vestiges of the irrigation systems, settlements, forts, caravanserai, and harbours associated with the production and distribution of incense has been comprehensively studied in a number of specific regions across Arabia (Sedov 1992; Lightfoot 2000; Wilkinson 2003; Avanzini & Sedov 2004; Gunter 2005; Hardy-Guilbert 2005; Peacock, Williams & Bird 2007; Blom et al. 2007), little work has been done to determine the nature and scale of incense production on Socotra.

While archaeologists have attributed the presence of a series of walls spread out across the island as evidence of the cultivation and management of incense production on Socotra, no comprehensive study of these features has been attempted (Doe 1970: 151; 1992: 39–40; Naumkin & Sedov 1993: 584). To address this lacuna, the current project has undertaken an analysis of the walls using satellite remote sensing with brief targeted field visits to map the walls in association with settlements, water-related features, and other elements of the natural and cultural landscape. The results of our preliminary investigations are outlined in this paper.

Location and climate

Having a surface area of 3650 km^2, Socotra, the main island of the Socotra archipelago, is the second largest island in the Western Indian Ocean (Othman 1996: 204). The island is characterized by the Ḥajhir (Hagher), a granite mountain range that stretches across its centre in a west-south-westerly to east-north-easterly ridge and rises up to 1550 m (Miller & Morris 2004: 6). Bordering the Ḥajhir is an undulating plateau of limestone that ranges from 300 to 900 m and covers almost half of the island's surface (Beydoun & Bichan 1970: 414). The northern and southern coastal plains of Socotra are distinctly different. Along the northern side of the island there are a series of small coastal plains that are bordered by the aforementioned limestone escarpments along their landward side and separated from each other by rocky headlands along their seaward extent. Conversely, the southern coastal plain consists of a single wide plain that stretches approximately 80 km along the southern side of the island and reaches approximately 6 km inland where it terminates against a sheer limestone cliff (Cheung, Devantier & Damme 2006: 31).

Situated within the Inter-Tropical Convergence Zone, Socotra is influenced by two distinctly different monsoon seasons, the south-west (winter) and north-east (summer) monsoon season (Fleitmann et al. 2004). During the south-west monsoon period, from June to September, hot and dry winds scour the island causing temperatures to soar. During this period, water is particularly scarce, as most available water resources dry out and life becomes extremely hard for the inhabitants (Morris 2002: 16). During the north-east monsoon season, from October to April, the wet tropical monsoon winds bring high rainfall and cause temperatures to drop. The greatest precipitation during this period mainly occurs during October to January, after which rains gradually begin to decrease with the onset of the south-west monsoon. Summer rains occur mostly along the northern part of the island, although in April and May they can occur in the south (Mies & Behyl 1996: 40). The average annual rainfall varies greatly between the coast and interior plains, which receive approximately 170 mm, and the mountains, which receive approximately 1500 mm. Rainfall in the mountains generally occurs in the form of short convection thunderstorms that result in violent flash floods. The high precipitation in the mountains is also the result of dews, drizzle, and fogs that, especially during the south-west monsoon, can contribute up to 357–567 mm of moisture (Scholte & De Geest 2010: 1514). This precipitation is especially important during the dry season as it generates a slow but persistent surface runoff, which is often the only source of water in the Ḥajhir and surrounding limestone plateaus (Rossini 2014: 29). The apparent regularity of the rainfall as outlined here is not always a true reflection of life on the island and it is not uncommon for the north-east monsoon rains to fail, an event which brings extreme hardship to the islanders.

Historical background

Incense was one of the most important luxury items of exchange in antiquity, forming part of a hugely profitable trade that stretched from the Mediterranean and Red Sea regions to Mesopotamia, India, and China, and flourished from the second millennium BC to the first millennium AD (Groom 1981; Gupta 2007). Historical accounts indicate that the island of Socotra formed an important part of this trade, producing incense in such abundance that it could supply the entire inhabited world (Diodorus Siculus 1933–1967: 5.41.4). This trade is also mentioned in the Periplus (mid-first century AD), which refers to Arab, Indian and Greek settlers, who sailed out to Socotra to trade in these items and other commodities (Casson 1989: 6). The only source that alludes to the production of incense, however, is Diodorus Siculus (*c*. first century BC) who remarks that the land of Socotra is divided among its inhabitants and that the king takes for himself the best land and likewise a tithe of the fruits which the island produces (Diodorus Siculus 1933–1967: 5.42.5). Archaeological evidence for Socotra's involvement in the Indian Ocean trading networks is exemplified by recent findings in the Hoq (Ḥūq) cave on the north coast of Socotra (Strauch 2012). The large corpus of inscriptions of sea-traders from India, South Arabia, Ethiopia, Egypt, and Palmyra, dating from the first century BC to the sixth century AD, found within the cave, attests to both the importance of Socotra and the extent of its trading networks (Strauch 2012). The decline of the incense trade appears to have had a significant impact on Socotra's primary export, but it was soon replaced by a burgeoning demand for Socotrian aloes, which was appreciated throughout Eurasia for its medicinal properties (Schoff 1922: 171–185). This demand grew exponentially through the Middle Ages up until the nineteenth century, with up to two tons a year having been exported (Lloyd 1898: 5). While Socotra enjoyed a short-lived period of self-governance in the sixteenth century, for the most part it has remained under the dominance of rulers from the ḤaPramawt, or the Sultans of Mahrah, who either leased it out to foreign merchants or governed this trade themselves (Casson 1989: 69; Tibbetts 1981: 223; Serjeant 1996: 144).

Exploration: background

Archaeological research on Socotra began in the nineteenth century with the explorations of Lieutenant Wellsted (d.1842) who, while surveying the interior, commented on the proliferation of stone walls that he believed served as boundaries to the aloe grounds (Wellsted 1835: 167). Following this survey, the traveller and archaeologist Theodore Bent visited the island seeking evidence for a Himyarite and Christian civilization (Bent & Brisch 2010: 279). While these aims were not realized, he did observe that the interior was terraced by numerous walls and interpreted these as evidence for Socotra having supported a larger population in the past (Bent 1900: 351–352). The next archaeological survey took place in 1956 as part of a joint Oxford and Cambridge team led by the explorer Douglas Botting, who also noted the presence of terrace walls. Drawing on his knowledge of the importance of the incense trade in Socotra's history, he surmised that they were built to prevent erosion and provide areas within which incense trees could be planted and tended (Botting 2006: 185). The archaeologist for this expedition, P.L. Shinnie, while having surveyed and excavated only on the north coast, concurred with these findings, remarking that it was significant that the stone walls and terraces occur only at an altitude which is suitable for the growth of incense trees (Shinnie 1960: 103). Shinnie also suggested that these structures might have functioned as field boundaries, marking the territory between different tribal groups (1960: 106). In 1964–1965 Brian Doe, the Head of Antiquities in Aden, undertook several archaeological excavations and a survey of numerous sites along the northern half of Socotra. The presence of 'vast areas encompassed by alignments of stone walling' also attracted his attention (Doe 1983: 250). Doe claimed that the walls represented the efforts of a large and well-organized labour force, and were clearly the physical manifestation of the delineation of title to land for the groves of incense, aloes, and dragon's blood trees mentioned in the historical sources (1983: 250; 1992: 47). Using aerial photography, Doe began to map the extent of the walls in the immediate vicinity of Dihūb, an ancient settlement on the western plateau. This not only demonstrated the potential for mapping these walls using aerial photography, but also their relationship with early settlements, or 'central farmstead complexes' (1992: 12, fig. 1; 54–55). Further archaeological work was undertaken by a joint Soviet-Yemeni team that, over a period of several years, extended their investigations along the island's western and central parts (Naumkin 1993; Naumkin & Sedov 1993). In the publication of these archaeological investigations, Naumkin and Sedov refer to the presence of walls and their associated structural remains and go so far as to agree with Doe's hypothesis that the walling of the interior is likely to date to a period when Socotra was a major supplier of aloe, incense, and dragon's blood (Naumkin & Sedov 1993: 584). In spite of these numerous archaeological expeditions to Socotra, virtually no survey of the southern half of the island was undertaken. This was noted by Weeks et al. (2002), who carried out an archaeological survey of portions of the south-west, central, and eastern regions in 2001. During this expedition he too noted the stone wall alignments found throughout the island. Unlike previous authors, however, he refers to both the variation in their location and the diversity in their configuration. According to his report there are those that look like 'roads', others that appear to be 'field systems', and some that are 'clearly retaining walls'; all of which occur in a variety of environmental zones that include arid coastal plains, scrub-covered limestone plateaus, and humid mountainous areas (Weeks et al. 2002: 122). Interestingly, he also remarks that the Socotri appear to recognize this diversity and differentiate between the long wall lines (*eggehon*), the small enclosures of old walling (*mahger*, pl. *mehaagir*), and the larger circular paddocks or old field systems (*ma'ariqoh*, pl. *me'oriq*).

What is evident from these reports is that despite numerous archaeological expeditions and multiple theories on their use, there has been no systematic study of the stone wall alignments on Socotra. Moreover, other than Doe's mapping of the walls in the vicinity of Dihūb, there has been no attempt to map the variety of wall types or the locations in which they are found. By considering wall type, location, and the local environmental context we can begin to provide new insights into their use.

Remote sensing

The usefulness of aerial photographs and satellite remote sensing for the identification of archaeological sites and landscape features across the Middle East has been clearly established (see Hritz 2014; Comer & Harrower 2013; Wilkinson 2003). On Socotra, the potential of remote sensing was first demonstrated by Doe, who utilized aerial photographs to map the walls and features around the ancient settlement site of Dihūb on the western plateau (Doe 1993: 12, fig. 1; 54–55). The wider use of this methodology was also suggested by Weeks et al. (2002: 122) as the key to a better understanding of the enigmatic wall systems of Socotra. Mapping such an extensive series of walls over the entire island was recognized as an immensely time-consuming task. Over the course of eleven years, however, our colleague Dirk Van Dorpe, a caver who has worked extensively on the island, identified and traced *c*.4460 km of wall alignments on high-resolution satellite imagery, freely available on the Google Earth platform. The mapped walls appear on the imagery as dark or light lines, generally no more than 2 m in diameter. The variation in colour is associated with environmental conditions in different parts of the island. The walls found at higher altitudes, which usually receive greater amounts of precipitation and fog, have a thick growth of white lichen on them, while those in arid and low-lying areas are usually devoid of any growth.

The resultant data was incorporated into a Geographical Information System (GIS) (Esri ArcMap 10.0–10.3) along with digital elevation data, and the locations of sites and landscape features identified by previous archaeological surveys. This has allowed us to identify areas of high archaeological interest, and begin to place the walls and archaeological sites within the context of the wider landscape. The benefits of this aerial perspective are that it allowed us to see the relationships between features that are often obscured at ground level. Coupled with brief, targeted field visits this has also allowed us to gain a fuller understanding of these wall systems with respect to the physical landscape.

Results

The results of the wall mapping can be seen in Figure 1. At this scale, it is clear that the walls are mainly concentrated on the eastern limestone plateau, and seem to spread in a south-westerly direction along the southern escarpment. In the west, although the walls appear to be much more fragmented, they too appear to be primarily concentrated on the limestone plateaus. Some walls are located at much lower altitudes, however, both within the west central and north-eastern areas of the island. Despite these discrepancies it is clear that the majority of the walls are found at an altitude of around 300–900 m above sea level (asl). To understand the reason for this, it is necessary to look closer at the types of wall systems, the relationship between them, and the ecological zones in which they are found.

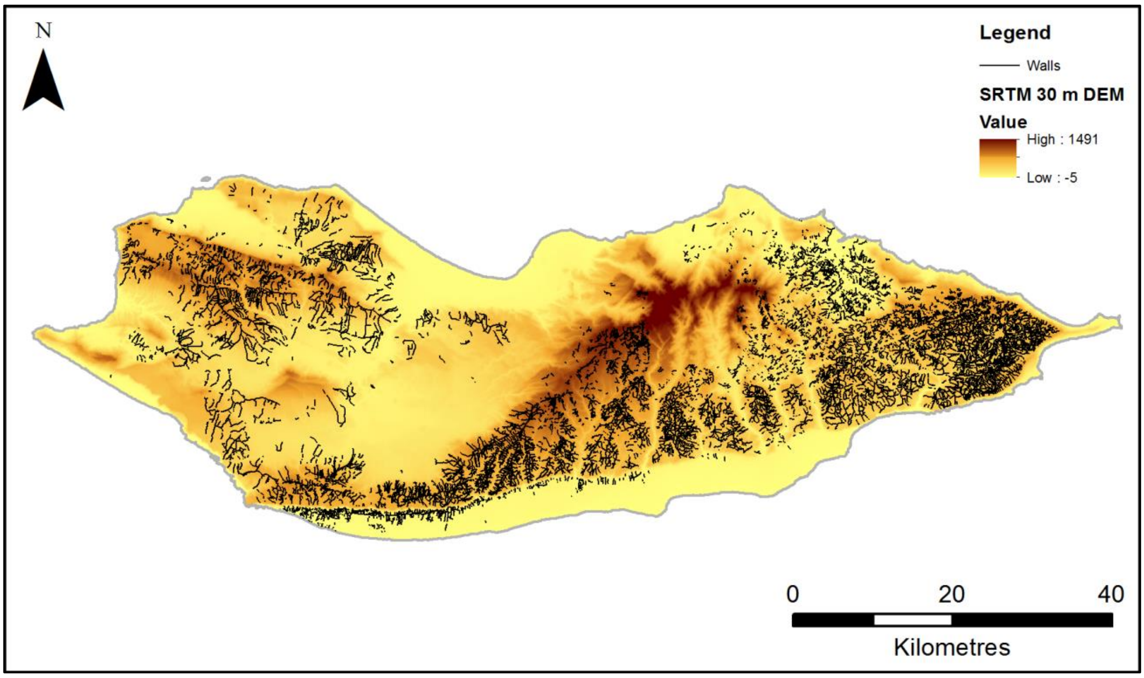

Figure 1: Distribution of wall systems on the island of Socotra displayed on a SRTM 30 m DEM (available from the US Geological Survey).

Types and functions of wall systems

While a systematic analysis of the walls is ongoing, at this preliminary stage in our investigations we have been able to identify several key types that appear with frequency. These can be categorized as follows:

— enclosures;

— walls related to water features;

— field systems and trackways, often incorporating double wall lines.

Enclosures

Across the island there are a number of walls that can be characterized as enclosures (Fig. 2). These exist in a range of shapes and sizes but they are frequently irregular. Groupings of these features, found particularly on the eastern part of the island, are generally no larger than 100 m in diameter on their longest side. While it was possible briefly to visit some of these features, there was no indication as to what function they may have served, although it may be that, as Weeks et al. (2002: 122) reported, they are paddocks. They may also represent the remains of farmsteads, or settlements, and in at least one instance these features correspond to a site identified by Weeks et al. (2002: 100, fig. 3) as ‘stone structure(s)’. Additionally, they could have served as collection points, or even nurseries for incense trees, as has been suggested by Mies, Lavranos and James (2000: 268), but without further ground-truthing and excavation these theories must remain suppositions.

Figure 2: Examples of enclosures and structures mapped from the satellite imagery.

Walls related to water features

It was also clear that among the profusion of walls there were a number that had been built across wadi streams. This had also been observed by Bent (1900: 383), who recorded how, in some areas, particularly within the interior, walls of approximately 2.5–3 m in width were built across streams to stem the torrent of water that occurs during the rainy season. This would certainly seem to indicate that these walls would have functioned as check dams or diversion channels for the episodic flash floods that occur during the north-eastern monsoon.

In several areas we also noticed that there was a series of ‘long walls’ that radiated out from a central point (Fig. 3). During ground-truthing we found that these walls converged on large, shallow depressions that were sometimes filled with water. According to Morris (2002: 32), these large basins, or *leem*s, were often augmented with a stone lining, and are one of the oldest forms of water management on the island. Considered to have been built by the ‘ancients’, *leem*s have been recorded by several expeditions that have remarked both on their size and, in some cases, proximity to ancient settlements (Wellsted 1835: 152, 171; Bent 1900: 383; Brown 1966: 6; Weeks et al. 2002). In several instances, radiating 'long walls' may now be directly associated with these *leem*s, and can be seen to be extremely effective in diverting water from surface runoff into the *leem*s (Fig. 3).

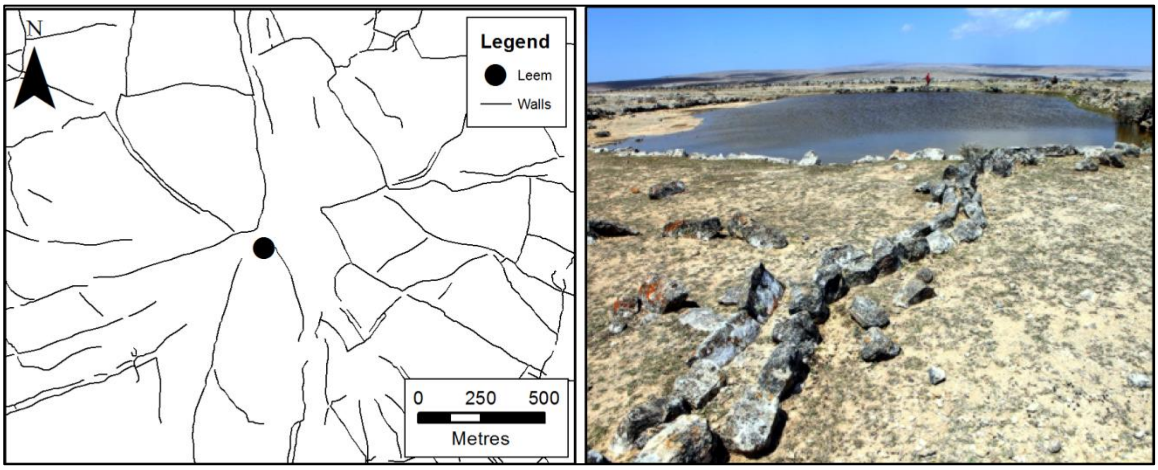

Figure 3: Walls converging on a *leem* mapped on satellite imagery, and an example viewed in the field (photograph by Vladimir Melnik).

Field systems and trackways

Wall alignments interpreted as ancient field systems can be found throughout the island (Fig. 4). These are characterized by a series of shorter parallel stone walls running perpendicular to longer (often double) wall lines. It is likely that these walls were built during field clearance and functioned as field boundaries. Fields with permanent stone boundaries are common in marginal landscapes across the Near East where there is an abundance of stone material (Wilkinson 2003: 53).

The alignment of these systems varies across the island. On the western limestone plateau, the parallel short walls appear to run downslope or toward wadis (Fig. 4/a). Examples from the southern limestone plateau also appear to run toward wadis, but are orientated perpendicular to the general slope of the land (Fig. 4/b). In some contexts these walls appear to have aided in soil and water retention, although it is unlikely that this was the sole function of these features in all contexts.

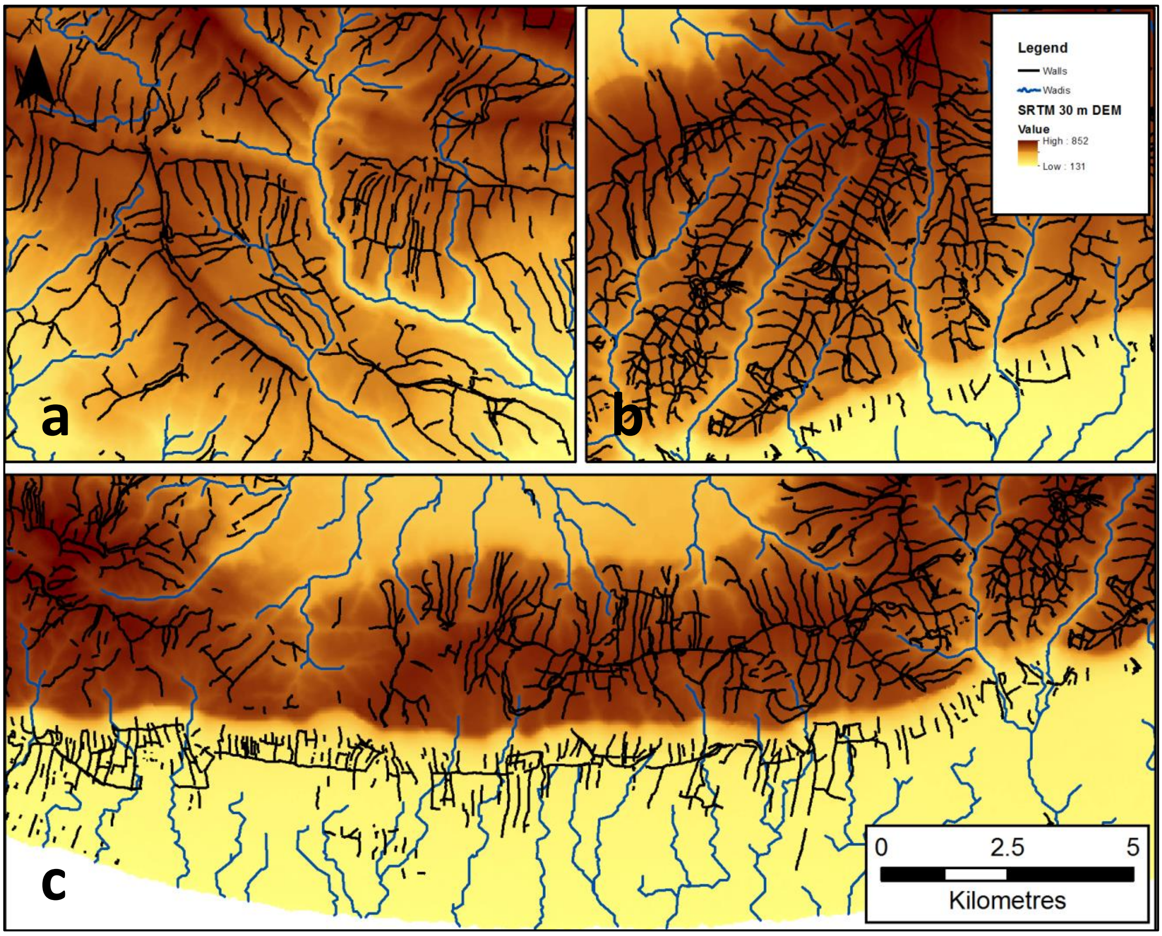

Figure 4: Examples of field systems mapped on satellite imagery: a. an example of field systems on the western limestone plateaux; b. field systems on the southeastern limestone plateaux; c. the field systems located along the southern coastal plains. Base map SRTM 30 m DEM (available from the US Geological Survey).

The accumulation of sediments in and around the stone walls on the island had been noted by Pietsch and Morris (2010: 379), who interpreted this as a side-effect to the seemingly unknown purpose of the walls. We would argue that in some circumstances this was the intended outcome, especially as strategies for the conservation and exploitation of soil resources for the growing of crops are well known from the Yemen mainland from as early as the fourth millennium BC (Wilkinson 2003: 55). Indeed, surveys of the island by Botting (2006: 165), Doe (1970: 153), Brown (1966: 6), and Weeks et al. (2002) all refer to ancient retaining walls and terracing throughout the island. This effect may also explain the differential preservation of field systems across the island. During a field visit to the western part of Socotra it was apparent that one of the possible reasons for the dearth of walls on the satellite imagery in this area was their burial by sediments.

The primary function of these field walls, however, may have been to delineate ownership of land. This interpretation is reinforced by the double wall alignments, which we find associated with these field systems. First identified by Doe (1992: 99), the double wall alignments consist of two parallel stone walls that lie approximately 50 m apart and run for several kilometres (Fig. 5). We identified several examples of these double wall alignments on the imagery, the majority of which formed the ‘spine’ or long-wall portion of these field systems and frequently appeared to run along the top of slopes. Interestingly, a watershed analysis utilizing a 30 m Digital Elevation Model (DEM) generated from Shuttle Radar Topography Mission (SRTM) data showed a correlation between the double wall alignments and boundaries of sub-basins of watersheds. This suggests that a detailed understanding of local water resources played a role in delineating field boundaries.

Similar types of double wall alignments (though not associated with field systems) have been identified in mainland Yemen by Wilkinson (2003: 60–61), who classifies them as ancient rural tracks. The interpretation of these wall systems as tracks would seem to be justified, in that these double wall alignments appear to create a route that would allow access to the field systems without having to cross the surrounding fields. These tracks are used by the local inhabitants today, who use them as drove ways to move their livestock across the island. They may also have served a similar function in the past, and could have been used to keep livestock from grazing within the bounded fields and damaging plants under cultivation. The tops of ridges are also likely to have provided the easiest route through the landscape. Overall these walls seem to have served a number of different functions at different periods of time. Having established the function of a number of these wall alignments, we can now consider their location within specific ecological zones of the island and their potential role in historical incense and aloe production.

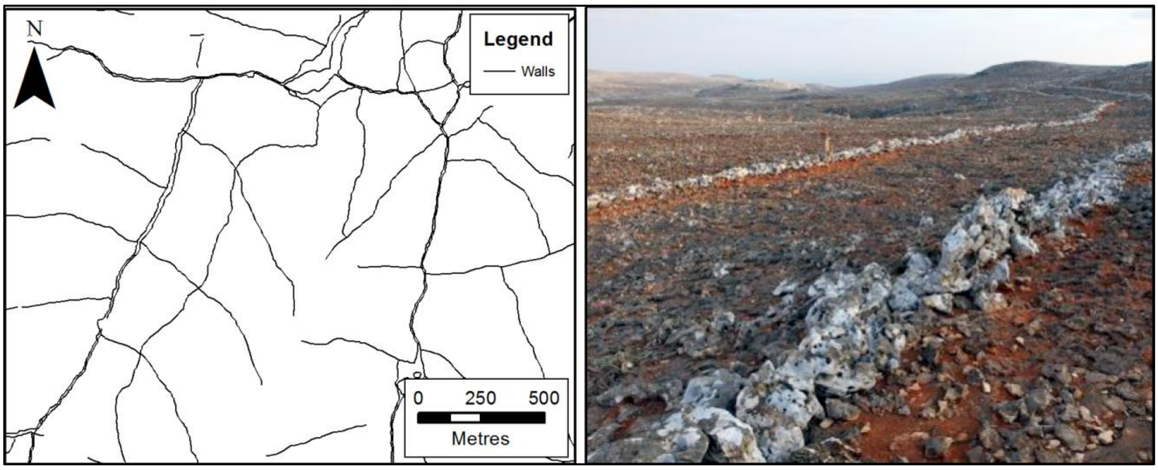

Figure 5: Double wall lines forming possible trackways mapped on satellite imagery, and an example viewed in the field (photograph by Vladimir Melnik).

Ecology

Due to the unique biodiversity found on Socotra there have been a number of expeditions undertaken, from as early as the nineteenth century, to study its unique and endemic fauna and flora (for a complete reference list see Miller & Morris 2004). As a result, we have a relatively accurate understanding of the ecological distribution of the various species on the island (see Král & Pavliš 2006; Brown & Mies 2012; De Sanctis et al. 2013). Consequently, it is possible to map the modern distribution of the main species that, according to the historical sources, were being exploited on Socotra from as early as the first century BC, namely: *Boswellia elongata*, the *Boswellia* species producing the most valuable incense; *Dracaena cinnabari*, known as Indian cinnabar, or dragon's blood; and *Aloe perryi*, the famed Socotran aloe, which was being exported in huge quantities throughout the Middle Ages.

Looking at the distribution maps for *Boswellia elongata* and *Dracaena cinnabari* it is clear that they are both found within an altitudinal belt of between approximately 300 and 700 m (Attorre et al. 2011: 1493, fig. 3; Brown & Mies 2012: 218, figs 6.3; 6.143), but while *D. cinnabari* are generally found on rocky limestone slopes and cliffs, *B. elongata* tends to grow on flat areas (Brown & Mies 2012: 218; De Sanctis et al. 2013: 152). Interestingly, both species are generally restricted in their distribution to the eastern half of the island, although isolated occurrences of *D. cinnabari* are recorded in the south-west. When we compare the distribution patterns for the current population of these two species with the distribution of walls, and in particular wall systems we have identified as field boundaries, it is clear that there is a correlation. It may well be that the walled field systems along the southern escarpment of the limestone plateau are an indication of the relictual distribution of one or both of these species.

Conversely, the Socotran aloe — *Aloe perryi* — is very patchily distributed throughout the island. Generally, populations are found in dry areas, on flat or gentle slopes, primarily on limestone pavement but occasionally on sandy plains or in the granite mountains up to an altitude of 900 m (Miller 2004; Brown & Mies 2012: 222). A series of walls located at lower altitudes (less than 300 m asl) on the southern coastal plain may represent the traces of field systems delineating areas in which *Aloe perryi* was being grown and harvested (Fig. 4/c). Moreover, it could also be argued that, due to the variety of habitats within which *Aloe perryi* can grow and the burgeoning trade in aloes during the Middle Ages, there was a later revival of wall construction, as was pointed out by Wellsted (1835: 167).

While it is unlikely that all the wall systems observed on Socotra were specifically related to the production and exploitation of incense, dragon's blood, and aloe, an understanding of the distribution of these species, particularly in relation to likely field systems, is certainly instructive. The correlation between the modern plantations of *Boswellia elongata* and *Dracaena cinnabari* and the density of wall construction on the eastern half of the island suggest that this may have been the main area in which these species were being exploited.

Conclusion

The evidence reviewed above suggests that at least some of the wall systems mapped on the island of Socotra are indicative of the island having been intensively farmed for incense, dragon's blood, and aloes at some point in its history. Without independent dating evidence, however, it is impossible to confirm whether the walls are representative of one major building event, or the result of episodic use and reuse, perhaps over a considerable period of time. What is evident is that the walls not only served a variety of functions pertaining to the agricultural production and management of incense, dragon's blood, and aloes, but they were also being used in water management practices. This is clearly demonstrated by examples such as check dams, diversion channels, and walls leading to *leem*s. As the plant species discussed above tend to be able to thrive in relatively arid environments, however, it seems unlikely that these water management practices would all have been related to agricultural production. Instead, it could be argued that water management was important for sustaining the influx of seasonal workers that, according to Doe (1970: 151), would have come from the mainland to assist in the harvest of the above-mentioned crops. This would certainly support the historical evidence, which suggests Socotra was under the rule of the Ḥaḍramawt kingdom, and that it was being leased out to Arab traders (Casson 1989: 69). Our analysis of the wall systems found on Socotra is very much ongoing. Consequently, the preliminary results that have been outlined here must remain so. What is clear, however, is that remote sensing is a powerful tool for mapping extensive features such as these wall systems, a task that would be immensely time-consuming and expensive if using traditional ground-based survey techniques. Combining the archaeological data from previous surveys with targeted field visits and data from environmental and ecological studies, has allowed us to analyse these systems at multiple scales and begin to untangle the complex palimpsest of activities that have occurred in this landscape over time. Moreover, this approach has allowed us to continue our investigations despite the fact that the current conflict in Yemen has made access to the island impossible.

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References

Attorre F., Taleb N., De Sanctis M., Farcomeni A. et al. 2011. Developing conservation strategies for endemic tree species when faced with time and data constraints: Boswellia spp. on Socotra (Yemen). *Biodiversity Conservation* 20: 1483–1499.

Avanzini A. & Sedov A.V. 2005. The stratigraphy of Sumhuram: new evidence. *Proceedings of the Seminar for Arabian Studies* 35: 11–17.

Bent T. 1900. *Southern Arabia*. London: Smith, Elder and Co.

Bent T. & Brisch G. 2010. *The travel chronicles of Mrs. J. Theodore Bent*. Oxford: Archaeopress.

Beydoun Z.R. & Bichan H.R. 1970. The Geology of Socotra, Gulf of Aden. *Quarterly Journal of the Geological Society of London* 125: 413–446.

Blom R.G., Crippen R., Elachi C., Clapp N. et al. 2007. Southern Arabian desert trade routes, frankincense, myrrh, and the Ubar legend. Pages 71–87 in J. Wiseman & F. El-Baz (eds), *Remote Sensing in Archaeology*. New York: Springer.

Botting D. 2006. *The Island of the Dragon's Blood*. London: Steve Savage.

Brown G.H.H. 1966. Social and economic conditions and possible development of Socotra. [Unpublished circulated report].

Brown G. & Mies B.A. 2012. *Vegetation ecology of Socotra*. Dordrecht: Springer.

Casson L. 1989. *The Periplus of the Erythraean Sea*. Princeton: Princeton University Press.

Cheung C., Devantier L. & Damme K.V. (eds). 2006. *Socotra: a natural history of the islands and their people*. Hong Kong: Odyssey.

Comer D. & Harrower M. (eds). 2013. *Mapping Archaeological Landscapes from Space.* New York: Springer.

De Sanctis M., Adeeb A., Farcomeni A., Patriarca C. et al. 2013. Classification and distribution patterns of plant communities on Socotra Island, Yemen. *Applied Vegetation Science* 16: 148–165.

Diodorus Siculus/ed. and transl. C.H. Oldfather, C.L. Sherman, C. Bradford Welles, R.M. Greer & F. R. Walton. 1933–1967. *Bibliotheca Historica*. London: Heinemann.

Doe D.B. 1970. *Socotra: an archaeological reconnaissance in 1967*. Miami, FL: Coconut Grove.

Doe D.B. 1983. *Monuments of South Arabia*. Naples: Falcon.

Doe D.B. 1992. *Socotra Island of Tranquillity*. London: Immel.

Fleitmann D., Matter A., Burns, S.J., Al-Subbary A. & Al-Aowah A. 2004. Geology and Quaternary climate of Socotra. *Fauna of Arabia* 20: 27–43.

Groom N. 1981. *Frankincense and myrrh: a study of the Arabian incense trade*. London: Longman.

Gunter A.C. 2005. *Caravan kingdoms: Yemen and the ancient incense trade*. Washington, DC: Smithsonian Institution.

Gupta S. 2007. Frankincense in the 'triangular' Indo-Arabian-Roman aromatics trade. Pages 112–121 in D. Peacock, D.F. Williams & J. Bird (eds), *Food for the gods: new light on the ancient incense trade*. Oxford: Oxbow.

Hardy-Guilbert C. 2005. The harbour of al-ShĭHr, Ḥaḍramawt, Yemen: sources and archaeological data on trade. *Proceedings of the Seminar for Arabian Studies* 35: 71–85.

Herodotus/ed. and transl. A.D. Godley. 1920–1957. *The Histories*. London: Heinemann.

Hritz C. 2014. Contributions of GIS and satellite-based remote sensing to landscape archaeology in the Middle East. *Journal of Archaeological Research* 22: 229–276.

Král K. & Pavliš J. 2006. The first detailed land-cover map of Socotra Island by Landsat/ETM+ data. *International Journal of Remote Sensing* 27: 3239–3250.

Lightfoot D.R. 2000. The origin and diffusion of *Qanat*s in Arabia: new evidence from the northern and southern Peninsula. *The Geographical Journal* 166/3: 215–266.

Lloyd G.U. 1898. Aloe Succotrina. *The Western Druggist* 1–14.

Mies B.A. & Beyhl F.E. 1996. The vegetation ecology of Soqotra. Pages 35–81 in H.J. Dumont (ed.), *Proceedings of the First International Symposium on Soqotra Island: Present and Future, Aden 1996. Conservation and Sustainable Use of Biodiversity of Soqotra Archipelago, Technical Series*. i. New York: United Nations Publication.

Mies B.A., Lavranos J.J. & James G.J. 2000. Frankincense on Socotra Island (Boswellia, Burseraceae; Yemen). *Cactus Succulent Journal* 72: 265–278.

Miller A. 2004. *Aloe perryi*. The IUCN Red List of Threatened Species 2004. http://dx.doi.org/10.2305/IUCN.UK.2004.RLTS.T44896A10951424.en.

Miller A.G. & Morris M. 2004. *Ethnoflora of the Soqotra archipelago*. Edinburgh: The Royal Botanic Garden.

Morris M. 2002. Manual of Traditional land use practices in the Soqotra archipelago. Edinburgh. [Unpublished circulated report].

Naumkin V.V./transl. V.A. Epstein. 1993. *Island of the Phoenix: an ethnographic study of the people of Socotra*. Reading: Ithaca.

Naumkin V.V. & Sedov A.V. 1993. Monuments of Socotra. *Topoi* 70/3.2: 569–623.

Othman W.A. 1996. Hydrological conditions of Socotra. Pages 203–218 in *Proceedings of the First International Symposium on Socotra Island: Present and Future, Aden, 24–28 March, 1996.* ii. *Natural Resources and Environmental Protection*. Aden: University of Aden Printing and Publishing House.

Peacock D., Williams D.F. & Bird J. (eds). 2007. *Food for the gods: new light on the ancient incense trade*. Oxford: Oxbow.

Pietsch D. & Morris M. 2010. Modern and ancient knowledge of conserving soils in Socotra Island, Yemen. Pages 375–388 in P. Zdruli, S. Kapur, M. Pagliai & A. Faz Cano (eds), *Land degradation and desertification: assessment, mitigation and remediation.* Dortrecht: Springer.

Pliny the Elder/ed. and transl. H. Rackham. 1969. *Natural History*. London: Heinemann.

Ptolemy/ed. and transl. K.F.A. Nobbe. 1990. *Claudii Ptolemaei Geographia*. Hildesheim: Georg Olms.

Rossini L. 2014. Water management in a drought prone island. Pages 25–40 in F. Attorre (ed.), *Soqotra Archipelago (Yemen). Toward systematic and scientifically objective sustainability in development and conservation*. Rome: Edizioni Nuova Cultura.

Schoff W.H. 1922. Aloes. *Journal of the American Oriental Society* 42: 171–185.

Scholte P. & De Geest P. 2010. The climate of Socotra Island (Yemen): a first-time assessment of the timing of the monsoon wind reversal and its influence on precipitation and vegetation patterns. *Journal of Arid Environments* 74: 1507–1515.

Sedov A.V. 1992. New archaeological and epigraphical material from QanaM (South Arabia). *Arabian Archaeology and Epigraphy* 3/2: 110–137.

Serjeant R.B. 1996. The coastal population of Socotra. Pages 133–180 in R.B. Serjeant & G.R. Smith (eds), *Society and trade in southern Arabia*. Aldershot: Variorum.

Shinnie P.L. 1960. Socotra. *Antiquity* 34/134: 100–110.

Strauch I. 2012. *Foreign Sailors on Socotra: the inscriptions and drawings from the cave Hoq*. Bremen: Hempen.

Tibbetts G.R. 1981. *Arab navigation in the Indian Ocean before the coming of the Portuguese: being a translation of Kitāb al-FawāMid fī uṣūl al-baĦr wa l-qawāKid of AĦmad b. Mājid al-Najdī*. London: Royal Asiatic Society.

Weeks L., Morris M., McCall B. & Al-Zubairy K. 2002. A recent archaeological survey on Soqotra. Report on the Preliminary Expedition Season, January 5th–February 2nd 2001. *Arabian Archaeology and Epigraphy* 13/1: 95–125.

Wellsted J.R. 1835. Memoir on the Island of Socotra. *Journal of the Royal Geographical Society* 5: 129–229.

Wilkinson T.J. 2003. *Archaeological landscapes of the Near East*. Tucson, AZ: University of Arizona Press.

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